DESIGN OF A 5000 K. W. ISOLATED STEAM POWER PLANT

BY

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THE DESIGN OF A 5000 K.W. ISOLATED STEAM POWER PLANT TO BE MORE ECONOMICAL THAN CENTRAL STATION SERVICE FOR A PROPOSED NEW YORK HARBOR MANUFACTURING CONCERN

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A THESIS

Presented By

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To The

President And Faculty

of

ARMOUR INSTITUTE OF TECHNOLOGY

For The Degree Of

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

Having Completed The Prescribed Course of Study In

ELECTRICAL ENGINEERING

1916

H. M. Raymond

PREFACE.

The subject taken up in this thesis is a problem which must be worked out by manufacturing concerns located where central stations have grown to such size that they have undertaken to supply power to large installations:- which is the more economical, to build and operate a power plant or to buy the service and energy from the central station. A special case is taken up and the solution worked out in three parts.

In Part I is given the special conditions of the individual case and a general survey of the problem.

In Part II, the design of the plant is taken up, the calculations necessary are given and the reasons for various choices outlined.

In Part III, the question of the relative economy of the plant designed and central station service is discussed. The cost of the plant is given, the annual charges figured and the saving over the central station shown in this particular case.

H. B.

H. S. K.

S. N. A.

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Part I.

1. Subject of Thesis.

This thesis is the design of an isolated steam power plant to conform to the requirements laid down in the accompanying sheet issued by the Engineering Society of Western Pennsylvania and to serve the general purpose outlined.

2. General Conditions.

The typical daily load curve is not given but since it is specified that the plant must be able to carry the maximum demand of 5000 K.W. continuously, it is not permissible to provide for a smaller capacity with a view of carrying the peak load of comparatively short duration at approximately 25% overload. Since the plant being designed is to be located in New York City, in addition to the general engineering problems, consideration must be given to the city ordinances and to the public policy of the place. In general, it is difficult to obtain accurate data on the purchase price and installation cost of the different machines and equipment connected with such a plant when not actually in the market, so that any calculation of the cost and economy of plant must be

relatively a rough estimate.

ENGINEERS' SOCIETY OF WESTERN PENNSYLVANIA

COMPETITION IN ENGINEERING PROBLEMS

Department of Electrical Engineering

Issued ....

Returned ....

See Rules and Conditions attached hereto.

DESIGN OF ISOLATED POWER PLANT

A manufacturing concern is building a factory at the water's edge on New York harbor.

The plant will require power for operating motors running in size from 3 h. p. to 1000 h. p.

The plant operates from 7:00 o'clock Monday morning until 4:00 o'clock Saturday afternoon continuously.

The maximum power requirement will be 5000 kilowatts. The total kilowatt hours per year of the plant will be 14 000 000.

Electric power is purchasable in the form of 3-phase, 2200-volt, 60-cycle alternating current at the following rates:

A flat charge of $16.00 per year per kilowatt maximum demand plus a charge of ¾¢ per kilowatt hour for the actual energy taken.

For the purpose of determining the method of supplying power to the plant it is necessary to ascertain the cost of power generated by an isolated plant to be installed by the manufacturing company. The conditions affecting the cost of generating power are as follows:

Coal of 14 000 B.t.u. heating value per pound can be delivered at the plant for $3.00 per ton.

Wages in the power plant will have to be as follows:

Chief Engineer	$3000 per year
Engineer in charge of each shift	1500 per year
Firemen, each	1200 per year
Oilers and water tenders, each	900 per year
Common labor	20 cents per hour

Buildings and foundations will cost:

For the engine and generator room	$5.00 per sq. ft.
For the boiler room	4.00 per sq. ft.

Interest, insurance, taxes, maintenance and amortization taken collectively must be allowed for as follows:

On buildings and foundations	8%
On apparatus and equipment	15%

Design and estimate the cost of and cost of operation of a power plant to furnish the required power and give total annual cost of the power produced by the power plant, and of the purchased power.

The plant must have sufficient reserve capacity to permit full operation continuously.

A lighting load of 250 kilowatts on Saturday and Sunday nights must be provided for.

SOLUTION OF PROBLEM

The solution shall be written on 8½ in. by 13 in. sheets of white paper, typewritten sheets preferred, fastened together at the top, the several parts being bound separately and properly marked.

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SOLUTION OF PROBLEM

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All answers, specifications, etc., shall be made in a brief and concise manner.

THE SOLUTION TO CONSIST OF:

SUMMARY OF RESULTS: A brief summary of results shall be given on not more than three sheets of paper.

ESTIMATE OF COST OF PLANT: An itemized estimate of the cost of the plant shall be given, enumerating the number, size and cost of the principal pieces of apparatus, and, without itemized enumeration, the estimated cost of all piping, wiring and labor of installation.

COST OF OPERATION: A detailed accurate estimate of the cost of operation of the plant shall be made, showing the amounts of labor, fuel and supplies required, and, as briefly as possible, the means by which the figures are determined.

DRAWINGS: Blueprints of not more than three drawings, on sheets 24 in. by 36 in. are to be furnished. These shall include:

Plan view of the power house showing location and number and arrangement of the units.

Cross-section of engine and boiler room.

Wiring diagram of the electrical installation. A general design only is desired, and details of piping, wiring, etc., are unnecessary.

Contestants are at liberty, and are expected, to refer to all technical publications and other sources of general information bearing on the solution of this problem.

Within space 3½ in. high and 5 in. wide in the lower right-hand corner of the drawings, the following title is to be placed:

ENGINEERS' SOCIETY
OF
WESTERN PENNSYLVANIA
ELECTRICAL ENGINEERING PROBLEM
1915-1916
Solution Number (   )

The same wording to be used for heading of Summary of Results, Estimate Sheet, Calculations, etc.

METHOD OF JUDGING SOLUTIONS TO PROBLEM IN ELECTRICAL ENGINEERING

In judging solutions the following schedule will be used:

1. Engineering judgment	3 points
2. Method of solution	3 points
3. Accuracy of work	3 points
4. Neatness of work and answer	1 point
Total	10 points

Part II.

1. Choice of Units

The matter of economy overbalancing any additional flexibility in operation which a large number of units might give, only two of the possible combination were given any practical consideration. The advantages of installing five units of 1000 K.W. capacity each are:- first, no excess capacity is required; second, the units all being the same, a minimum supply of parts for repair need be kept; and third, there is a certain advantage in operation in having the units all exactly alike.

The advantages of installing two 2000 K.W. units and two 1000 K.W. units are:- first, less space is required for the four units than for the five; second, four units will require less attention than five and in general there is less danger of breakdowns and trouble the fewer the machines; third, it is the contention of the designers that the 6000 K.W. capacity in four units, the amount of auxiliary equipment being less, would be practically as cheap as 5000 K.W. in five units; fourth, there is the advantage of having a spare

unit.

In flexibility of operation one combination has no advantage over the other. After weighing the relative advantages of the two possibilities the designers chose the combination of the two 2000 K.W. units and the two 1000 K.W. units.

2. Choice of Boilers.

From current practice, as determined from conditions in similar installations discussed in technical magazines especially from editions of "Power" for the last two years, a pressure of 200 pounds gauge and 150° Fahr. superheat were chosen as conservative values for the condition of the steam. From tables and examples in Gebhardt's "Steam Power Plant Engineering" with steam under the assumed conditions, 15 pounds per kilowatt-hour was adopted as the steam consumption.

The number of boiler horsepower necessary was calculated from the general formula:-

$$\text{B.H.P.} = \frac{\text{heat units required}}{\text{heat units in a standard b.h.p.}}$$

$$B.H.P. = \frac{W \times (H\ ct_1) \times P}{34.54\ H_1}$$

W Steam consumption per K.W.

H total heat of steam at 200# pressure.

C Specific heat of Superheat.

t_1 degrees of Superheat.

P K.W. capacity

H_1 total heat of steam at atmospheric pressure

34.5 weight of steam evaporated under standard conditions in 1 b.h.p.

Substituting values and solving the equation,

$$B.H.P. = \frac{15\ (1199\quad .5 \times 150)\ 5000}{34.5 \times 970.4}$$

$$= 2850$$

There are practically two general types which could be considered either vertical or horizontal boilers. Vertical boilers take up less ground space per horse power than the horizontal type, but if a Dutch oven or smokeless setting is required this advantage is lost in the space taken up by the setting. For this

reason Babcock and Wilcox horizontal fire tube boilers were chosen because of advantages in other arrangements, such as conveyors, coal bunkers in the plant.

Again because of economy in floor space it is desirable to install the minimum number of boilers. The matter of working boilers at overload is merely a proposition of furnishing the necessary draft to burn enough coal. The boilers themselves, may be worked under such conditions without undue deterioration as is shown by the fact that large central stations tend to run at overloads of from 75 to 100 per cent. Examples of such are:- The Northwest Station of the Commonwealth Edison Co. and the Blue Island station of the Public Service Company of Illinois. Most smaller isolated plants have used the rated output of boilers because of the unusual draft needed to overload them. However, some smaller plants have run at as high as 100% overload as the Cosmopolitan Electric plant and the Armour Glue Works plant of Chicago. Calculating the height of chimney needed to run at 100% overload, 248 feet was found necessary. It

was planned to build one 200 feet for smoke distribution and the rest could be provided mechanically. Considering the economy in space produced, the designers decided to provide for an installation such that on the peak load of 5000 K.W. will be carried by the boilers at approximately 200% of the manufacturers' rating. The number and size of boilers installed was determined as follows:-

Actual B.H.P. required = 2850

Manufacturers' rating = 1425

All boilers to be same size.

Possibilities -

6 - 300 B.H.P. boilers giving 1-300 B.H.P.reserve

5 - 400 B.H.P. boilers giving 1-400 B.H.P.reserve

4 - 500 B.H.P. boilers giving 1-500 B.H.P.reserve.

4 - 500 B.H.P. boilers were chosen for economy in space and attention.

3. Choice of Condensers and Accessories.

Rectangular surface condensers were chosen because they could be used to best advantage with the horizontal turbines and because they are in general use in such plants. Because of the economy in space condensers which had their condensate, vacuum and

circulating water pumps underneath them driven on a single shaft by an auxilliary high pressure non- condensing turbine, were chosen.

Two exciters are provided, one motor driven and one turbine driven, each capable of carrying the total exciting current.

A Stillwell horizontal open feed-water-heater is provided for to heat the boiler feed water. The horizontal type was chosen because it could be placed in the basement without extending up through the boiler room floor. The feed water is to be taken care of by turbine driven boiler feed pumps. Two are to be installed each of capacity large enough to pump all the water needed.

Other auxilliaries chosen are of the types in general use and the size specified is that prescribed by the manufacturer for the purpose used.

4. Specification of Units.

Only the more general specifications are provided for by the designers. More particularly the requirements to which the units will be expected to meet will be given here and the more detailed

specifications left to the better judgment which experience has given the manufacturer.

The following are the general specifications of the 2000 K.W. unit:-

Type of Unit

2500 KVA - 3 Phase Generator to be driven by a steam turbine at 3000 R.P.M.

Extent of Work

The work includes the supply, delivery, erection and setting to work at the plant of two turbogenerators of the type specified.

Characteristics of Unit

Normal output	2500 K.V.A. or 2000 K.W.
Power factor of load	.8
Phases	3
Normal voltage	440
Voltage variation	420 - 460
Amperes per phase	2630
Speed	3600 r.p.m.
Frequency	60 cycles
Regulation -	The generator and exciter shall be shall be controlled by hand operated regulators.

Exciting voltage 125

The over-load and temperature rise are to be provided for as recommended in the Standardization Rules of the A.I.E.E.

Nature of Load

The generator is intended to supply power to a manufacturing plant adjacent to the power plant. The maximum load to be taken from the generators is 5000 K.W. at 440 volts. The plant is to operate continuously from 7:00 A.M., Monday until 4:00 P.M., Saturday and a lighing load of 250 K.W. is to be carried Saturday and Sunday nights.

The specifications of the 1000 K.W. units in the most part are the same as those of the 2000 K.W. units, thus only those specifications wherein they differ will be given in the following:-

Type of Unit

1250 K.V.A.- Three Phase Generator to be driven by steam turbines at 3600 r.p.m.

Extent of Work

The work includes the supply, delivery, erection, and setting to work at the plant of two turbo-

generators as specified above.

Characteristic of Unit

Normal output 1250 K.V.A.

Amperes per Phase 1315

Other characteristics exactly the same as in 2000 K.W. unit.

Nature of Load

Same as in 2000 K.W. unit.

5. Specification of Boilers.

As in the case of the units the specifications will be general rather than in detail. The service and requirements which the contractor will be expected to guarantee will be given and the detailed construction left to him. The general specifications are:-

1. Condition of Service

4 - 500 B.H.P. Babcock & Wilcox are to be arranged in batteries of two each, all in one row as shown on the main floor of the boiler room. The boilers are to be operated at 200 pounds gauge pressure, and furnish steam superheated 150° Fahrenheit.

2. Description and Material

The boilers are to be of the standard fire tube type provided with two steam drums each, and provided with the necessary superheater. Each boiler is to be supported from wrought iron beams of the building and left free to expnnd or contract entirely independent of, and

without affecting the brick work and arranged so that removal or repair of any portion of the brick setting in no way disturbs the boiler connections.

Each boiler will be furnished with the following fittings:-

All necessary safety valves; one steam gauge with 12 1/2" dial; two stand pipes with water gauges; a combination stop and check valve for each drum. The boiler setting and type of grate is to be such that it will meet requirements both in respect to nature of coal and local regulations in New York City.

Because of the severe conditions of operation the material and construction of the boilers must be the best. The steam header is to be formed of open hearth steel plate, forged to shape, with all joints made tight metal to metal.

All rivet holes are to be punched 3/16" under size and drilled to size and all burs removed and the plates assembled with parallel

turned bolts fitting the holes before rivetting. The transverse on round-about seams will be punched to the diameter of the rivet to be used. All rivetting is to be done by hydraulic presses and the rivet held until black. Each drum is to be fitted with a steam nozzle and safety valve nozzle.

All pipes to be extra heavy iron, pipe sizes connected with composition fittings without gaskets.

The Babcock & Wilcox superheater supplied with each boiler is to consist of seamless U tubes expanded into forged steel distributing and collecting headers. Hand holes are to provide easy access to the ends of the tubes and all parts are to be located conveniently for inspection and repair. Access to superheated chambers will be provided for by the proper dusting and cleaning doors.

All parts are to be tested and made tight under hydrostatic pressure before leaving the shop as follows:

Sections 400 pounds and drums 325 pounds; When erected complete on foundation, the whole structure to be tested and made tight at 325 pounds.

In the brick work to be provided by the contractor, the walls will be true to line and in every way a first class job. The joints are to be completely filled and are to be as thin as possible. All brick will be first quality hand burned with true surface and without cracks. No bats or bulged bricks will be used in any part of the setting.

The panels, splice plates, dead plates, and their chairs are to be of cast iron of a tough gray mixture. The clamps are to be of wrought steel. The casting are to be free from blow holes and other imperfections.

Guarantee

The contractor guarantees that each boiler will be capable of generating 25,000 pounds of steam per hour continuously at a pressure of 200 pounds gauge and a superheat of 150° Fahrenheit, which is 200% of the manufacturers' b.h.p. rating. That the boilers will be delivered and erected with grate and setting complete

at the plant and the work in every way will be the best.

6. <u>Specification of Condensers and Auxiliaries.</u>

The specification of the condensers and auxiliary apparatus will be confined to a statement of the requirements which must be met.

<u>Condensers.</u>

Two condensing outfits are to be provided each for a 2000 K.W. Curtis Turbo-generator, each capable of condensing steam from same at the rate of 30,000 pounds per hour and maintaining a vacuum of 28" of mercury when referred a 30" barometer, when supplied with condensing water at a temperature of 70° Fahrenheit. As stated, the condenser is to be a rectangular surface condenser with the circulating water pump, a condensate pump and a dry vacuum pump underneath driven on one shaft by a high pressure non-condensing turbine. The size of the auxiliaries to be determined by the manufacturer to fit the needs.

Two condensing outfits are to be provided exactly similar in requirements and description to those above except they are provided for 1000 K.W. turbines and are to condense steam at the rate of

15,000 pounds per hour. Their auxiliaries are to be provided for the same as above.

All condensers are to be provided with an automatic vacuum regulator and with a vacuum gauge.

Acceptance tests of the condensing outfits shall be conducted by representative of the Company and the Contractor on such lines as will be determined later.

Boiler Feed Pumps

Two turbine driven boiler feed pumps are to be provided, each with a capacity of 150 gallons per minute, operating against a head of 580 feet, approximately, or 250 pounds pressure and operating at a normal speed of 1650 r.p.m.

Each turbine will be furnished with an approved throttle and the necessary tools.

Each turbine is to be guaranteed against defects, either material or workmanship for one year.

The efficiency of the pump is not to be less than 65 per cent when delivering 150 gallons per minute against a head of 580 feet.

Governing devices are to be included so that the pump will be entirely automatic in its

operation when maintaining a constant discharge pressure.

Both pump and turbine will be mounted on a single bed plate of cast iron and the turbine is to be connected to the pump by a flexible coupling.

The turbine is to be designed for 200# steam pressure at the throttle and 150° F. superheat and under these conditions and no back pressure the contractor shall guarantee the turbine to use not to exceed 32# of steam per brake horse power.

FEED WATER HEATER

A Stillwell horizontal open feed water heater is to be provided capable of raising 1200 cubic feet of water from 40° to 212° Fahrenheit per hour. A suitable oil separator is to be provided at the steam inlet.

Other Auxiliaries

The circulating pumps, sump pumps and other auxiliaries will be chosen from the manufactuers catalogue on the rating given.

7. Calculation of Chimney

The height of the chimney is calculated for the

extreme conditions of peak load when one 500 B.H.P. boiler is supplying steam for 1/3 of the total load or 1667 K.W. or 950 B.H.P. which is overloading the boilers 90 per cent. The constants giving the necessary draft in inches of water were changed to fit the overload condition.

The cross sectional area is calculated on the height determined above. The actual height of the chimney is arbitrarily set at 200 feet and the equivalent of the other 50 feet furnished by a mechanical draft.

Calculation of Chimney -

1. Area of Grate Surface 9 x 8.5 76.5

2. Pounds of water per hr. 1667 x 15 25,005#
   200 lb. gauge - 150° F. superheat.
   Heat units per hour
   $$\left[(1199.2 + .5 \times 150) - (212-32)\right] \times 25,005$$
   $$= 24,810,000 \text{ B.T.U.}$$

3. Coal needed.
   Heat units per lb. of coal = 14000

   Boiler eff. = 70%

   Coal per hr. $= \dfrac{24810000}{14000 \times .7} = 2538\#$

4. Pounds of coal per hr. per sq. ft. of Grate Surface

   $$= \frac{2538}{76.5} = 33.2 \text{ lb. per hr.}$$

5. Pressure needed (inches of water)

See Gebhardt pp. 251 - Fig. 155
Use chain grate, bituminous slack

Furnace	.54
Boiler (assumed)	.64
Flue (100 ft.)	.10
Turns. (2)	.10
	1.38 inches of water

$\frac{1.38}{.8}$ = 1.72 inches of water (taking into account (.8) the loss in chimney.)

5. Height of Chimney

$$D. = H \times \left(\frac{7.64}{T_2} - \frac{795}{T_1} \right) = H\left(\frac{7.64}{520} - \frac{7.95}{1060} \right)$$

$$H = \frac{1.485}{.0072} = 248 \text{ feet}$$

6. <u>Cross Section</u>

$$4/3 \times 5000 = 3.33 \ E \sqrt{250}$$

$$E = \frac{4 \times 5000}{3 \times 3.333 \sqrt{250}} = 127.5$$

$$\frac{\pi D^2}{4} = 127.5$$

$$D^2 = 162$$

Effective D = 12.7 feet

Actual = 12.7 + .33 = 13 ft.

8. <u>Calculation of Steam Header and Pipes</u>

The preliminary assumptions necessary to deter-

mine the size of steam header and piping to units are the pressure, superheat and the velocity of the steam. The formulas used were taken from Gebhardt's "Steam Power Plant Engineering".

1. Conditions assumed

Pressure	=	200 pounds gauge
Superheat	=	150° Fahrenheit
Velocity	=	10,000 ft. per min. (Geb.Art 375)

2. Specific Volume of Steam

$v = v_1 \times (1 + .0016\ t)$ Gebhardt pp 194

$t = 15$

$v = 2.138\ (1 + .0016 \times 150) = 2.65$ cu.ft. per lb.

3. Steam Per Kilowatt Hour

15 pounds -

Gebhardt - pp. 449

Table 75 - Item 8

4. Diameter of Main Header

Assume uniform diameter.

Total steam per hr. = 15 x 5000 = 75,000#

velocity = 10,000

cu. ft. steam main $= \dfrac{75000 \times 2.65}{60} = 3310$

Crossection $= \dfrac{3310}{10000} \times 144 = 47.7$

= 7" diameter.

Calculation of steam pipe to 2000 K.W. unit.

Reference: Formula 11, p. 712, Gebhardt.

W = lbs. of steam per minute $= \frac{15 \times 2000}{60} = 500$

Assume $d = 9''$

$L = 1700 \times \frac{9}{12} + 30 = 1300$

$P_1 = 170$

$P_{\cancel{x}} = P_1 - P_2 = 3$

$y = .3738$

Solution

$$500 = 87 \times \left(\frac{.3738 \times 3 \times 191^5}{1300\left(1 \quad \frac{3.6}{9}\right)} \right)^{1/2} = 87 \times \left(\frac{66100}{1820} \right)^{1/2}$$

$$500 = 87\ (6.01) = 522.$$

$d = 9''$ is approximately correct.

Calculation of steam pipe to 1000 K.W. unit.

Assume $d = 6.5''$ and substitute in same formula as above.

$W = 250\#$ of steam per minute.

Other terms as above.

$$250 = 87 \left(\frac{.3738 \times 3 \times (6.5)^5}{1300\left(1 \quad \frac{3.6}{6.5}\right)} \right)^{\frac{1}{2}}$$

$$250 = 87 \times \left(\frac{13100}{2020} \right)^{\frac{1}{2}} = 220$$

$d = 7''$ is approximate correct.

Description of Plant

The power plant building is to be of steel and brick resting on a concrete foundation. The roof of the boiler room and of the turbine room are both to be of slate and supported by steel roof-truss. The steel frame work and roof truss is to be self supporting and independent of the brick work.

The brick work is to be made of common brick decorated around the top with a design in pressed brick. The brick wall is to be 18" wide at the main floor.

The turbine room is 124 feet long and 31 feet wide with the narrow side along the harbor, and the turbo-generators arranged with their long dimension parallel to that of the room. The main floor is replaced with a concrete re-enforced platform connecting the units and running the length of the room extending three feet beyond the units on the side. The condensers and auxiliaries are located in the basement underneath the units. The switch board if centrally located along the wall next to the boiler room. Below it in the basement is the turbine driven exciter while the motor driven exciter is further down the room.

The boiler room joins the turbine room on the

left, looking towards the harbor, and is 83.5 feet long and 60 feet wide. The two batteries of boilers are side by side facing the wall away from the turbine room.

The coal bunkers are supported over the boilers by steel trusses and I beams upon which is also carried the conveyor. In the basement behind the boilers in the end of the room away from the harbor is the feed water heater and the boiler feed pumps. Plenty of light is supplied by windows in the outside wall and in the roof.

The section containing the coal hoist, the ash storage and coal crusher is built out from the boiler room on the harbor side over the conveyor and is 26 feet long and 28 feet wide. It provides in addition a drive-way where coal may be brought by auto-truck and dumped direct into the crusher. As shown by the accompanying prints the regular supply of coal is taken from boats by the coal hoist and dumped into the crusher through a chute.

The chimney is located in the space between the turbine room and coal hoist.

Switchboard design and Specification:

Desctiption of Switchboard.

The switch-gear is to be placed along the

wall of the generator room joining the boiler room. The switchboard will not be enclosed in a separate room, but will be centrally located along the wall in order to be easily accessible, whenever necessary.

The cables will pass directly from the generator units to the switchboard. The total output of the plant is handled thru three feeder panels. One of the feeder panels takes care of the lighting load of the plant and has a capacity of 250 K.W. The other two feeder panels divide the industrial load equally between them.

Specifications for Switchboard

1. Panels to be blue Vermont Marble
2. Instruments to have marine finish; to be dead beat and protected from stray fields produced by adjacent connections or bus bars.
3. Oil switches shall have kilowatt rupturing capacity based on the total rated output of plant. The switches shall withstand for one minute a potential test between the contacts and the frame, of at least four times the rated voltage of the circuit.
4. All switches shall be of such capacities as to

as to carry the one or two hour overload rating of the circuits to which they are connected, without undue temperature.rise.

5. Connection bars and wires shall be of sufficent crossection so that with a maximum load the temperature rise at no point will exceed 40° C above that of the surrounding air.

Generator Panel

Each of the two thousand K.W. generator panels is to be equipped with the following apparatus made by the General Electric Co.

1 - A.C. ammeter with 4000 ampere scale

1 - polyphase indicating wattmeter with 2500 K.W.scale

1 - A.C.Voltmeter with 750 volt scale

1 - D.C. field ammeter with 160 amp. scale

1 - Rheostat mechanism

1- 6 point synchronizing receptacle

1 - 250 volt 160 amp. field switch with discharge clips

1 - Governor control switch

1 - T.P.S.T. 4000 amp. non- automatic oil switch

2 - Current transformers (4000 to 5) amp.

Each of the one thousand K.W. generator panels is to have the following instruments:

1 - A.C. ammeter with 2000 amp. scale

1 - polyphase indicating wattmeter with 1200 K.W. scale

1 - A.C. voltmeter with 750 volt scale

1 - D.C. field ammeter with 85 amp.scale

1 - Rheostat mechanism

1 - 6 point synchornizing receptacle

1 - 250 volt 85 amp. field switch with discharge clips

1- Governor control switch

1 - T. .S.T. 2000 amp. non-automatic oil switch

2 - current transformers (2000 to 5) amp.

Instrumentsfor Exciter Panel -

2- 400 amp. type DH_2 ammeters.

1 - 150 volt type DH_2 voltmeter

2 - handwheels for field rheostats

2 - 4 point potential receptacles with one 4 joint plug

2 - T.P.S.T. 250 volt 400 amp. lever switches

Instruments for Industrial Feeder Panels -

1- polyphase indicating wattmeter with 5000 amp.scale

1 - D.P. instantaneous overload relay

1 - T.P.S.T. 5000 amp. automatic type oil switch

1 - Polyphase Watthour meter

2 - Current transformers (5000 to 5) amp.

Instruments for lighting load feeder panel.

1 - Polyphase indicating wattmeter with 500 amp. scale

1 - D.P. instantaneous overload relay

1 - T.P.S.T. 500 amp. automatic oil switch

1 - polyphase watthour meter

2 - current transformers (500 to 5) amp.

Instruments for Induction Motor starting panel -

1 - A.C. ammeter with 70 amp. scale

1 - S.P. time limit overload relay

1 - T.P.S.T. 70 amp. automatic
K5 oil switch

1 - current transformer (70-5) amp.

Wiring of Power Circuits

Shall be in accordance with city ordinances and rules of the "National Board of Underwriters."

Part III

Cost of Plant

The cost of the plant is to cover the total expenditure charged to the plant complete and ready for operation. The estimate here made is based on data obtained from several sources, each set being used to check and balance against the others. No concrete information could be obtained from the manufacturers as to prices because they regulate them somewhat to fit the particular job being bid for and because the designers were not in the market.

Part of the data was taken from hand books, part from the proceedings of the A.I.E.E. and part was obtained from parties connected with either the construction or operation of power plants who had become acquainted with various cost data.

Considerable weight is given the accompanying table compiled by H.G.Stott of the Interborough Traction Company of New York because of Mr. Stott's position and because the data is taken on New York City plants where this proposed plant is designed for and, therefore, would take into account local conditions.

The other table taken from the Standard Hand gives the detailed cost of boiler-rooms from a different angle in terms of boiler horsepower and is val--

POWER PLANT COST DATA.

Stand Hand Book Sec. 10 - 913

Table by H.G. Stott - Interborough Traction Company, New York

****

	Min.	Max.
1. Real Estate	3.00	7.00
2. Excavation	.75	1.25
3. Foundations, turbines	.50	.75
4. Iron & Steel Structure	8.00	10.00
5. Building (roof & main floor)	8.00	10.00
6. Galleries, floors & platforms	1.50	2.50
7. Tunnels, intake & discharge	1.40	2.80
8. Ash storage pocket	0.70	1.50
9. Coal hoisting tower	1.20	2.00
10. Cranes	0.40	0.60
11. Coal & Ash Conveyors	2.00	2.75
12. Coal & " Chutes	0.40	1.00
13. Ash cars, locomotives & tracks	0.15	0.30
14. Water meters, storage tanks, and mains	0.50	1.00
15. Stacks	1.25	2.00
16. Boilers	9.50	11.50
17. Boiler setting	1.25	1.75
18. Stokers	1.30	2.20
19. Economizers	1.30	2.25
20. Flues, dampers and regulators	0.60	0.90

21. Forced draft blowers, air ducts	1.25	1.65
22. Boiler, feed and other pumps	0.40	0.75
23. Feed-water heaters	0.20	0.35
24. Piping, traps & separators	3.00	5.00
25. Pipe covering	0.60	1.00
26. Valves	0.60	1.00
27. Main engines, reciprocating	22.00	30.00
28. Exciter engines	.40	.70
29. Condensers, borometric or jet	1.00	2.50
30. Condensers surface	6.00	7.50
31. Electric generators	16.00	22.00
32. Exciters	0.60	0.80
33. Steam-turbine units, complete	10.00	15.00
34. Converters, transformers, blowers	0.60	1.00
35. Switchboards, complete	3.00	3.90
36. Wiring for lights, motors, etc	0.20	0.30
37. Oiling system	0.15	0.35
38. Compressed air system and other small auxiliaries	0.20	0.30
39. Painting, labor, etc.	1.25	1.75
40. Extras	2.00	2.00
41. Engineering expenses & inspection	4.00	6.00

BOILER ROOM EQUIPMENT. COSTS PER RATED BOILER HORSE-POWER USING COAL FOR FUEL.

Table 909; Sec. 10 - 907; Standard Handbook.

****

	High	Low
Boilers exclusive of masonry setting	11.00	8.00
Superheaters	3.00	0.
Stokers	5.50	3.00
Masonry setting for boilers	3.50	2.00
Flues	1.50	.75
Stocks	4.00	2.00
Economizers	4.00	0.
Mechanical draft	3.00	0.
Feed Pumps	1.50	0.60
Feed Heaters	1.00	0.40
All piping and pipe covering	10.00	6.00
Coal chutes & ash hoppers	1.25	0.
Various, such as indicating and recording devices, damper regulator, ladders and runways, painting, etc.	1.00	.50
TOTALS - - -	50.25	23.15

uable in that manner as a check.

In an article, pp. 583, proceedings of the A.I.E.E. for May, 1916, comparting the cost of steam and hydro-electric plants,the author estimates the average cost of a steam plant at $45 per switchboard horsepower output or about $60.00 per kilowatt.

Pender's Handbook estimates the cost of power plant buildings at from 8 to 12 cents per cubic foot and gives an average of 50 to 100 cubic feet per kilowatt. For a 5000 kilowatt plant this gives the minimum cost of the building alone at $20,000.00 and a maximum of $60,000.00.

Perhaps the most accurate information at hand concerning the cost of the units and condensers is the exact cost of both 2000 K.W., 1000 K.W. units and the accompanying list of condenser prices which were for an installation made near Pittsburg by the General Electric Company. The designers in using this data assume that the cost of units or condensers installed and ready to operate would be no greater in New York than it was for a very similar plant near Pittsburg, since the distance from the place of manufacture would in no case be greater.

In making this estimate the designers intend to

follow rather closely Mr. Stott's table,making it fit the special conditions. It is understood that the table is compiled from data covering a considerable range in size of plants and that in general the maximum applies to the smaller plants. The plan adopted is to find about where between the limits this particular plant falls by calculating the cost per kilowatt of some of the details which are known as the real estate and foundation and the cost of units, knowing this it is planned to figure the cost of the other items per kilowatt at about the same relative position between the extreme values.

Although units with an aggregate capacity of 6000 K.W. are installed, the plant is designed for a maximum of 5000 K.W. and the size of the buildings and other equipment may be calculated on a 5000 K.W. basis.

The switch board cost is known with considerable accuracy and the estimate from the tables will not be taken since the low voltage of 440 volts makes it a special case.

The Detailed Estimate

(A) Cost of Real Estate and Foundation

Generator Room	3844 sq.ft @ $5.00=	$19,220.00
Boiler Room	5738 sq.ft @ 4.00=	22,952.00

Total = $42,172.00

Cost per K.W. = $8.43

Max. from table = 9.00

Ratio = .94

(B) Cost of Units

2 - 2000 K.W. units @ $63,500.00	=	127,000.00
2 - 1000 K.W. units @ $31,500.00	=	63,000.00
	Total -	$190,000.00

Cost per K.W. = 31.75

Max. from table = 37.00

Ratio = .86

Average approximate ratio = .90

In estim ting the cost of items connected with the plant when no exact figures are available about 9/10 of the maximum value in the table will be taken.

Detailed Estimate of Cost

A Numbers denote in table taken

B Cost per K.W.

C K.W. necessary

D Total cost

Cost of Building

See next page

Cost of Building

A	B	C	D
1&2&3	8.43	5000	42,150
4	9.00	"	45,000
5	9.00	"	45,000
6	1.50	"	7,500
7	2.52	"	12,600
9	1.80	"	9,000
		Total	$161,250

Cost of Equipment

A	B	C	D
8	1.35	5000	6,750
10	.50	"	2,500
11	2.50	"	12,500
12	.90	"	4,500
13	.20	"	1,000
14	.90	"	4,500
15	1.80	"	9,000
*16	6.00	"	30,000
*17	.90	"	4,500
18	2.00	"	10,000
20	.80	"	4,000
21	1.65	"	8,250

Cost of Equipment (Continued)

A	B	C	D
22	.70	5000	3,500
23	.35	"	1,750
24	4.50	"	22,500
25	.90	"	4,500
26	.90	"	4,500
30	6.25	6000	37,500
31&33	31.75	6000	190,000
32	----	---	2,750
35	----	---	6,000
36	.25	5000	1,250
37	.30	"	1,500
38	.25	"	1,250
40	1.50	"	7,500
41	2.00	"	10,000
42	5.40	"	27,000
		Total	415,000

Cost of Building	$161,250
Cost of Equipment	415,000
Total	$576,250

Item 16 and 17 are much smaller than the maximum in the table because of the small boiler horse-

power installation as discussed before under heading of boilers, the ratio being about 2000 to 3500.

2. Operating Charges

Because of absence of data on the subject cost of lubricants, cost of water and minor expenses will not be considered individually, but will be taken care of by adding 3% to the total known expense.

Cost of Fuel -

(a) It is assumed that the average kilowatt hour during the year will not consume more than 20 pounds of steam.

(b) It is assumed that the average boiler efficiency during the year will not be lower than 65%.

Heat in pound of steam = 994.2 B.T.U.

Heat per K.W. hour = 20 x 994.2 19884 B.T.U.

B.T.U. per year = 14,000,000 x 19884

= 278,000,000,000 B.T.U.

Tons of coal per year

14,000 B.T.U. per pound

$$= \frac{278,000,000,000}{14000 \times .65 \times 2000} = 16800 \text{ ton}$$

Cost @ 3.00 per ton = $50400

Cost of Labor

1	Chief Engineer	@	$3000	$3000
2	Engineers	@	1500	3000
3	Firemen	@	1200	3600
2	Oilers	@	900	1800
2	Laborers	@	630	1260
			Total	$12,660

Summary of Operation Costs.

Coal		$50400
Labor		12660
Extra	3%	1890
		$64,950

3. Annual Charges Against Plant

Interest, insurance, taxes, maintainances and amortization.

On building	.08	x	$161,250	$12,900
On equipment	.15	x	415,000	62,250
Operating expense				64,950
			Total -	$140,100

Annual Central Station Charges.

Energy used	14,000,000 K.W. hours
Maximum demand	5,000 K.W.

Maximum demand charge $16 per year per kilowatt

Energy rates 3/4 cent per kilowatt hour

Charges

5000 x 16	$80,000
14,000,000 x .0075	105,000
Total	$185,000

5. <u>Economy of Isolated Plant</u>

Annual Central Station Charge	$185,000
Annual Plant Charge	140,100
Saving per year	$ 35,000